Thermal Performance of Developed Carbon Nanotubes and Nanospheres Based Thermal Interface Materials for Heat Dissipation Applications

Department of Physics

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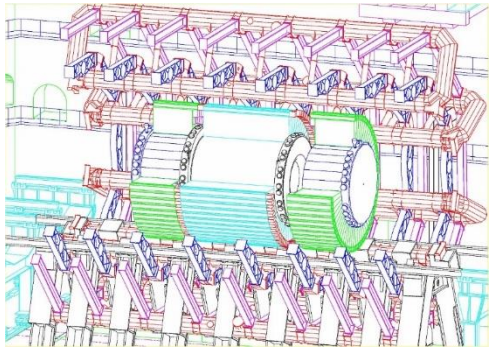
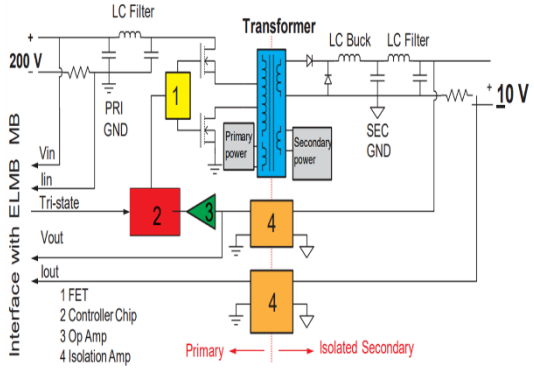
❑ ATLAS/TileCal Detector

- Particle detectors of the LHC accelerator had been designed to have integrated electronics.
- big constraints: continuous radiation exposure, very limited space, only water cooling available, and an external DC magnetic field from superconducting magnets.
- Protecting the electronics inside the detectors from damages and overheating, and expanding their lifespan, is required.

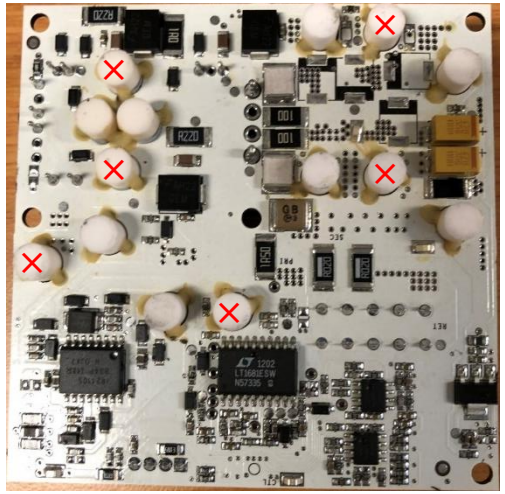
✓ **Continuous and good heat dissipation is necessary.**

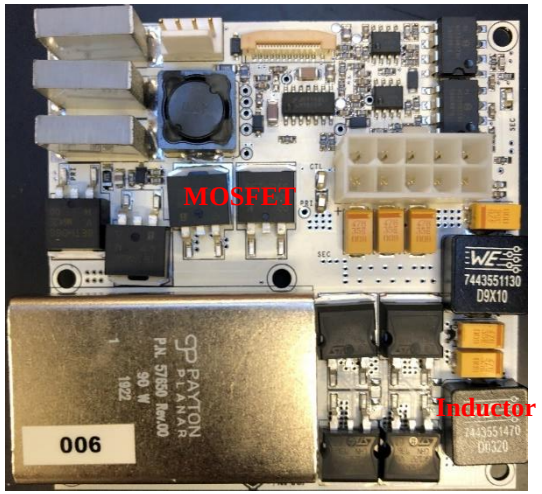




❑ Low Voltage Power Supply (LVPS)

- The LVPS brick is a 6 layer board with dimensions 80.26 mm square.
- The main electronic components are the transformer, MOSFETs and inductors.
- The thermal coupling between the electronic components of the brick and the cooling system is provided by means of alumina cylinders.
- The thermal posts are in contact with the rear of the electronic components via a third-party material referred as the Thermal Interface Material (TIM).

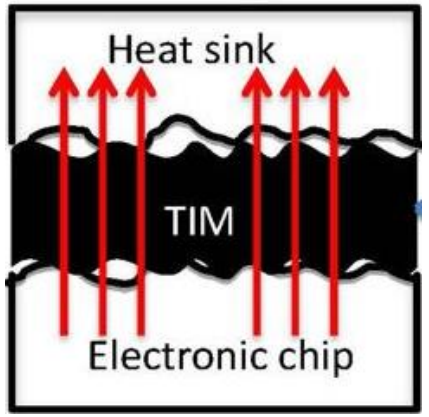


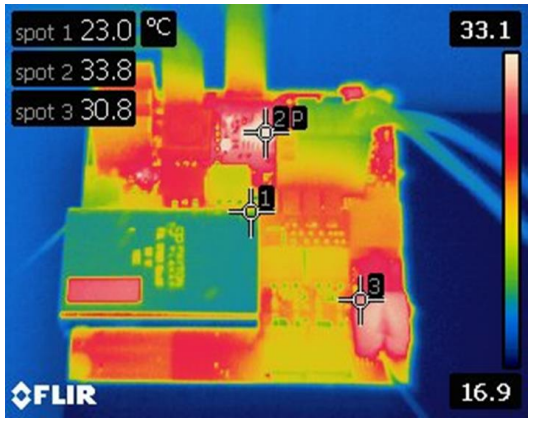


❑ Thermal Interface Materials (TIM)

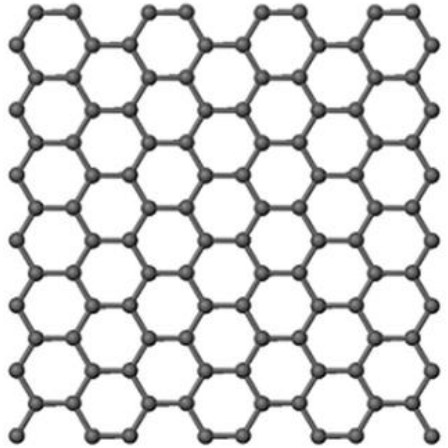
- Material utilised in between two interfaces in electronic devices.
- TIM are polymer or metal-based materials, filled with conductive particles.
- Protect expensive systems (overheating, damage…), expand their lifespan.
- Heat conduction coefficient of the Thermal Interface Material is considered low for many contemporary applications (micro- and nano-electronic…).

✓ **Integrating Carbonaceous Nanomaterials**





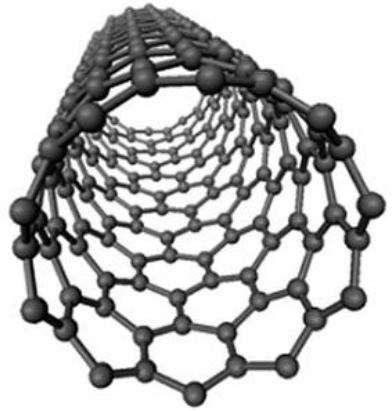
Carbon Nanomaterials



Global Nanotechnology Market & Forecast to 2024 [1]

- The global nanotechnology market is expected to exceed US$ 125 Billion mark by 2024.
- the nanomaterials captured highest share of the global nanotechnology market.
- Nanoparticles holds over 85% share of the global nanomaterials market.

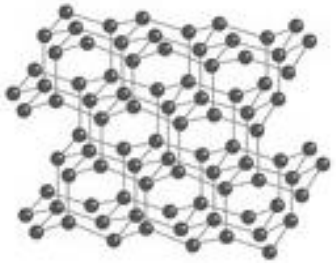
Carbon Allotropes

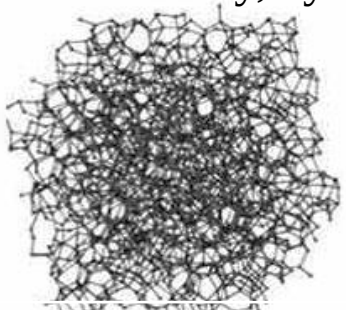


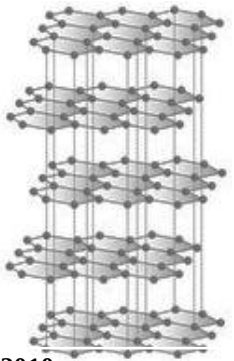
- **3D:** Graphite, Diamond, Amorphous Carbon.
- **2D:** Graphene, Carbon nanoribbons (unzipped carbon nanotubes).
- **1D:** Carbon Nanotubes (single and multi walled), Carbon Nanohorns.
- **0D:** Fullerene, Nanodiamonds, Carbon Dots, Carbon Nanospheres.

Applications

- Electronics, Energy, Biomedicine, as controlled/targeted drug delivery systems, supercapacitors, catalyst supports, superconductivity, hydrogen storage[1].

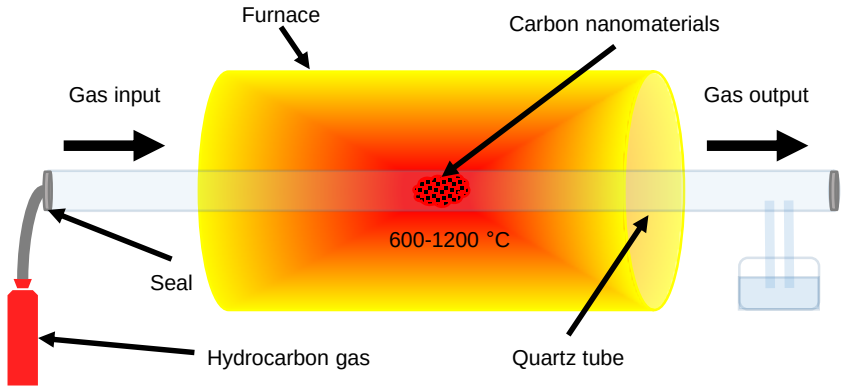


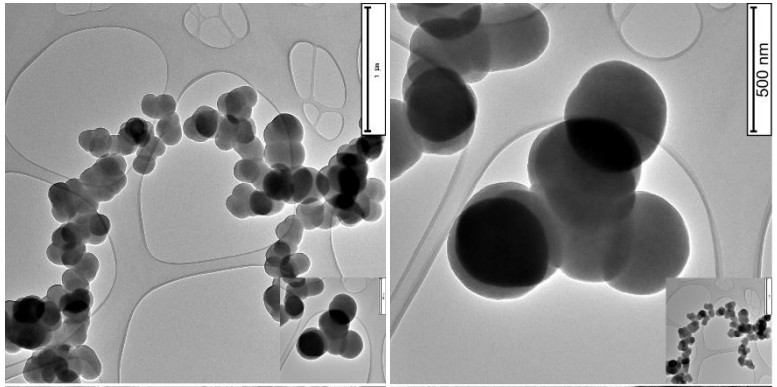


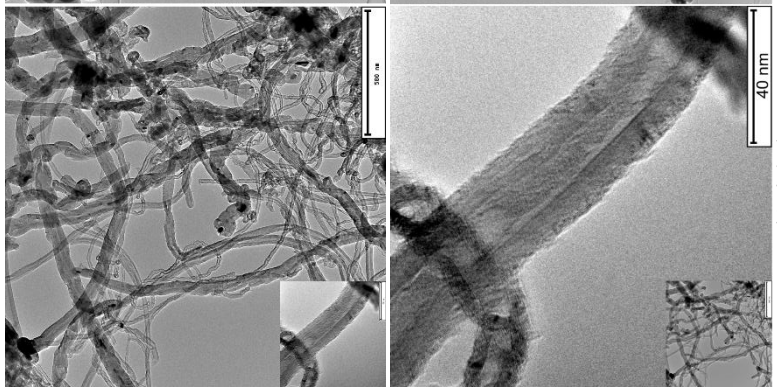


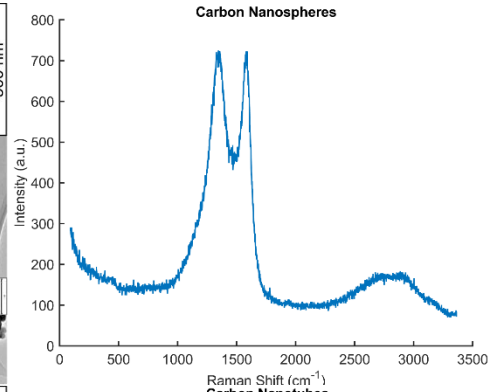
"A. A. Deshmukh, S. D. Mhlanga and N. J. Coville, "Carbon spheres," Materials Science and Engineering: R: Reports, vol. 70, no. 1-2, pp. 1-28, 2010.

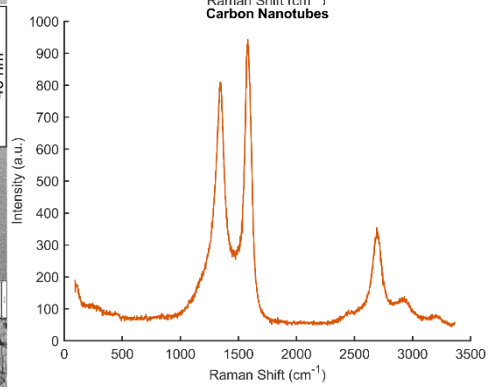
Preparation of TIM (Epoxy/CNMs)



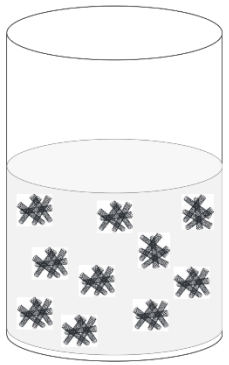




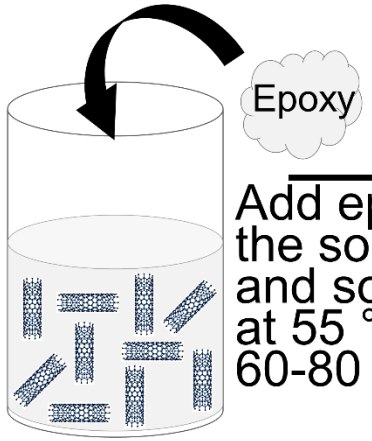




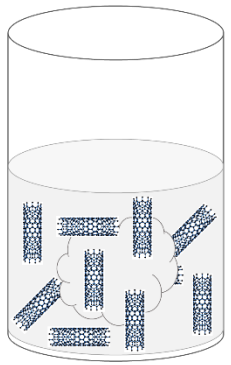
Add CNTs powder to 0.5 ml of Acetone.



Sonicate the solution for 30 min to disperse CNTs.

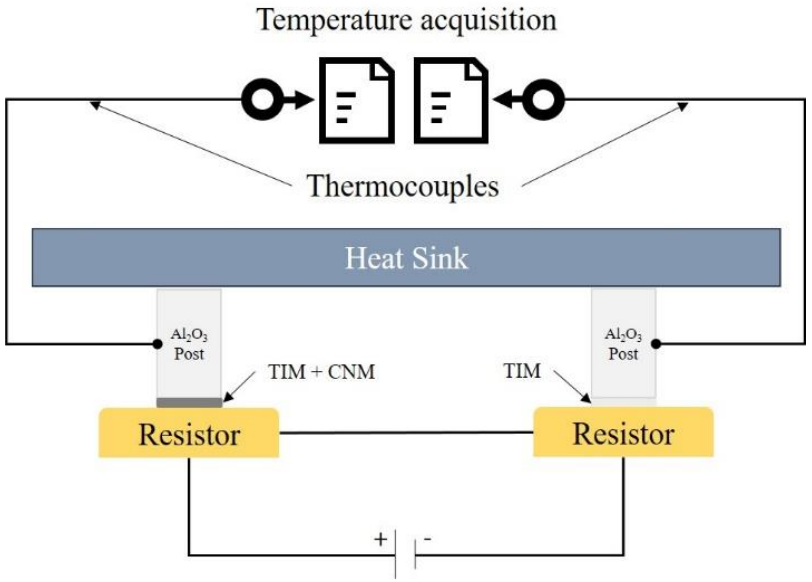


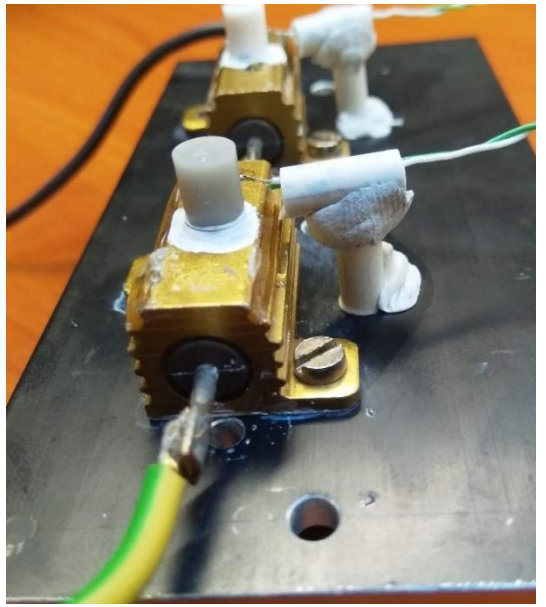
Add epoxy to the solution and sonicate at 55 °C for 60-80 min.

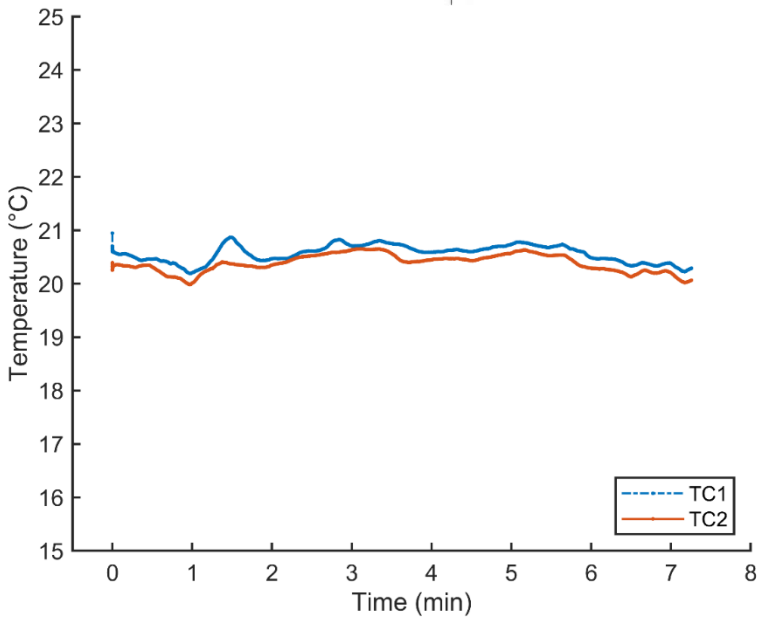


Mixture of CNTs/Epoxy allowed to rest for 10 h.

Experimental Setup







$Q \propto \Delta T$

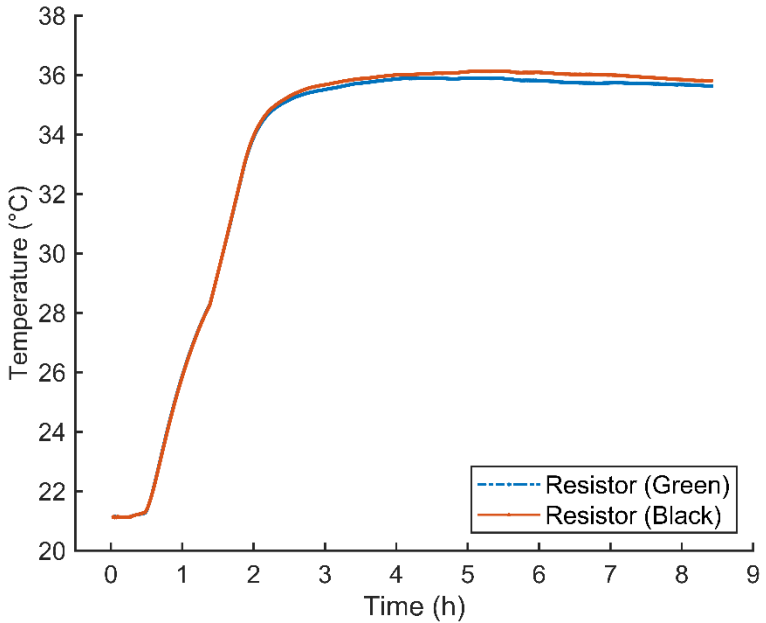
$\Delta T = T_{in} - T_{out}$

$\Rightarrow Q \propto 1/T_{out}$

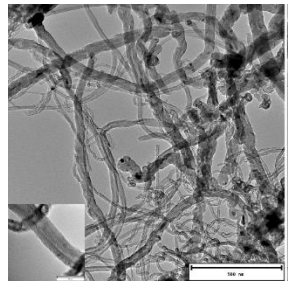
Q: Heat transfer

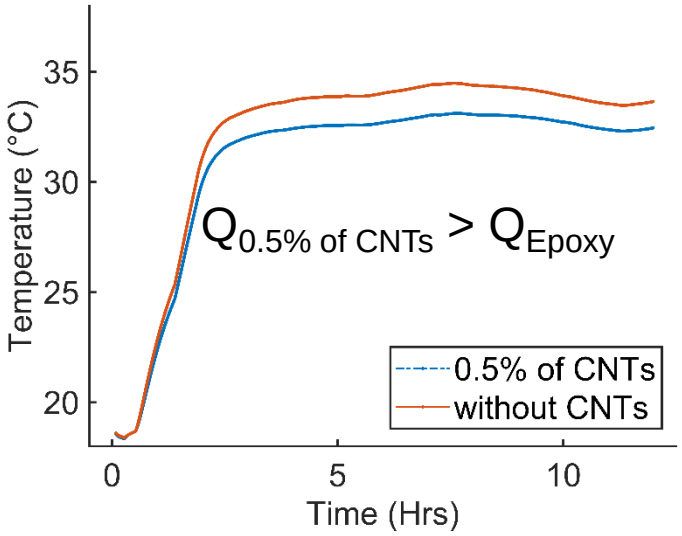
ΔT: Temperature gradient

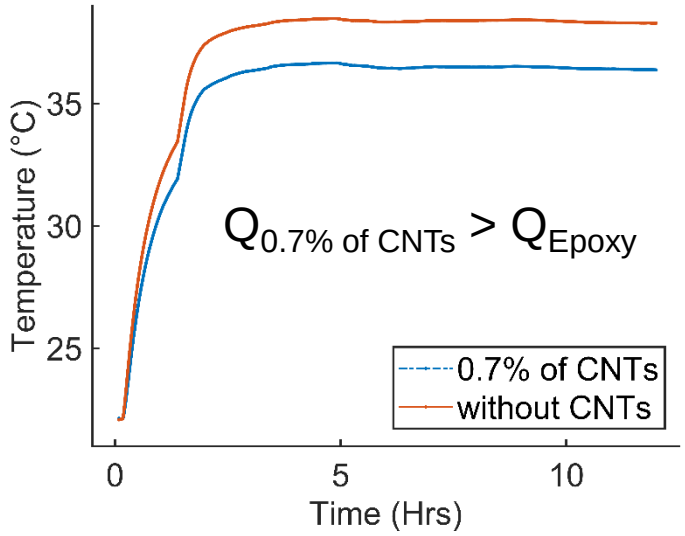
T_{out}: Temperature of the post

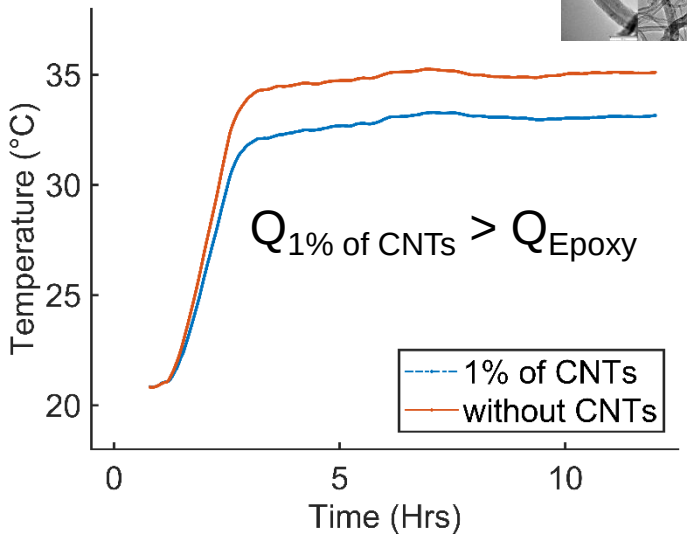


Results ($TIM_{with\text{-}CNTs}$ vs $TIM_{without\text{-}CNTs}$)

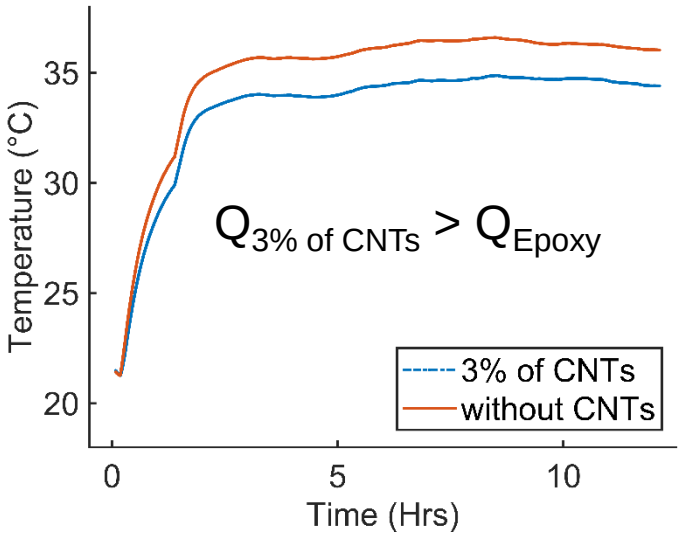


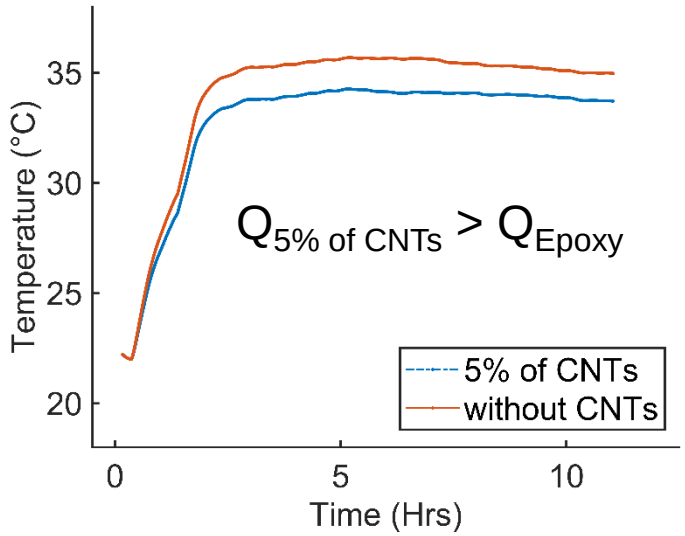


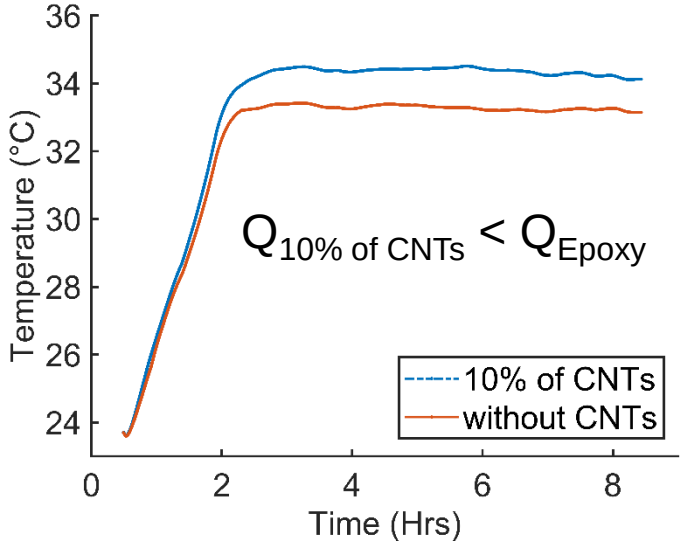




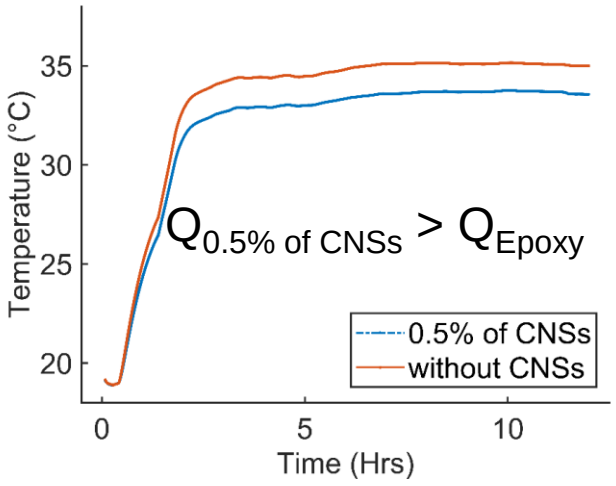
$$Q_{1\% \text{ of CNTs}} > Q_{5\% \text{ of CNTs}} > Q_{0.5\% \text{ of CNTs}} > Q_{epoxy} > Q_{10\% \text{ of CNTs}}$$

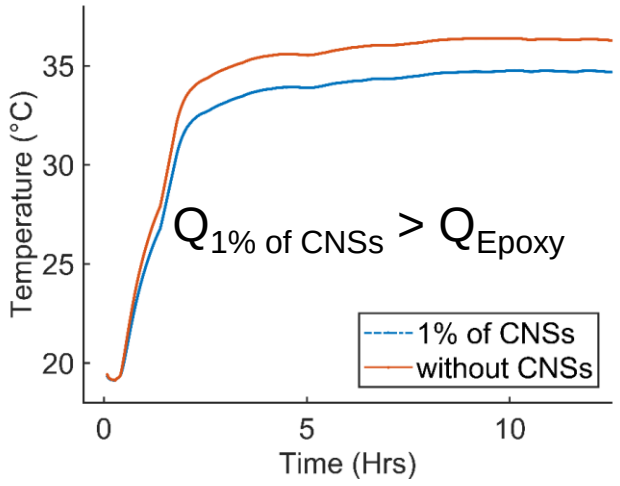




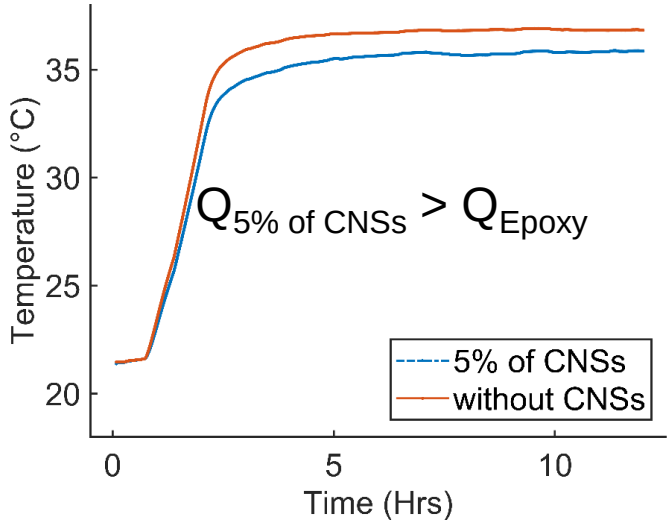


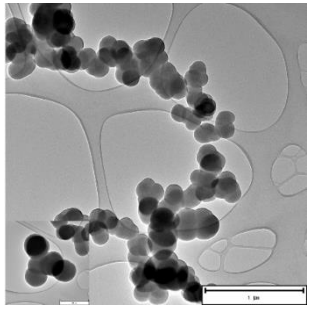
Results ($TIM_{with\text{-}CNSs}$ vs $TIM_{without\text{-}CNSs}$)



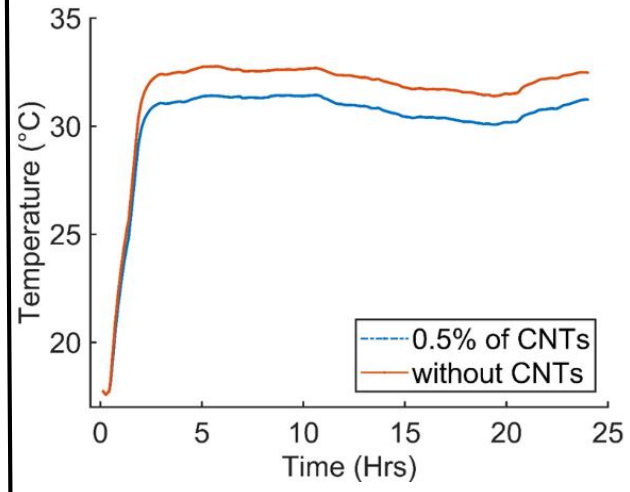


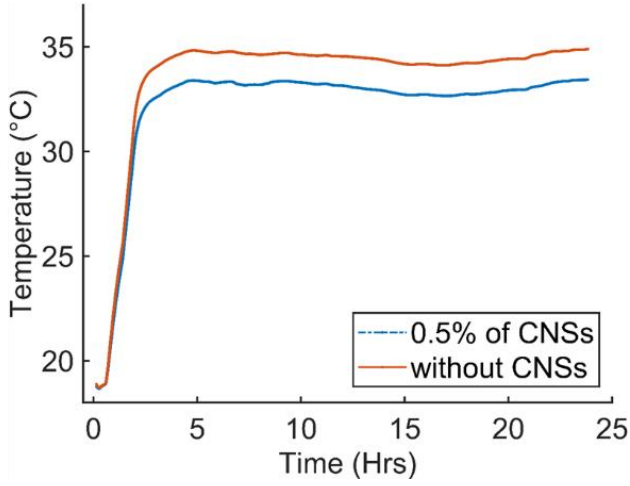
$Q_{1\% \text{ of CNSs}} > Q_{0.5\% \text{ of CNSs}} > Q_{5\% \text{ of CNSs}} > Q_{epoxy}$

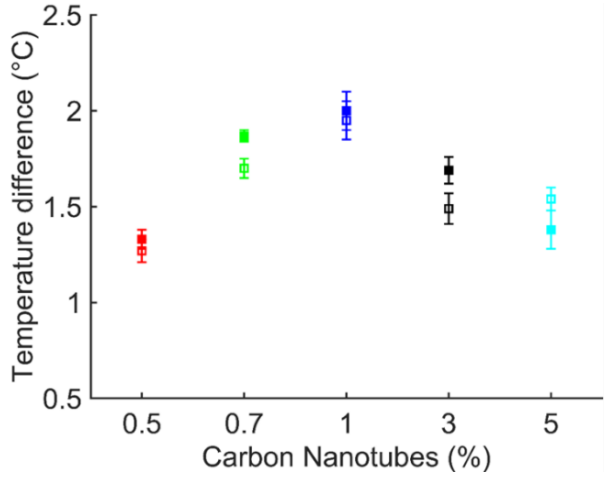


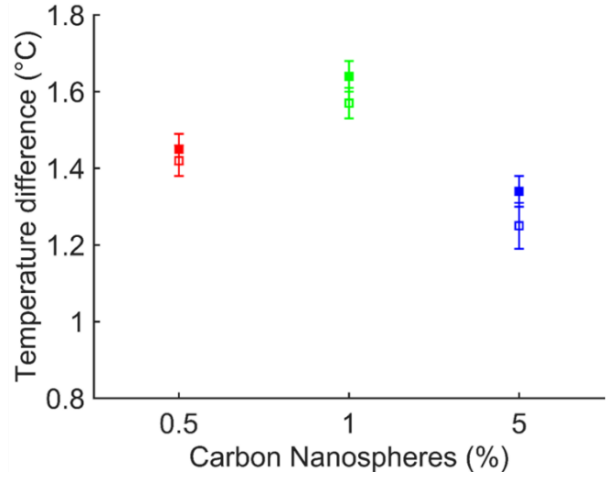


Reliability and Reproducibility of the Recorded Results



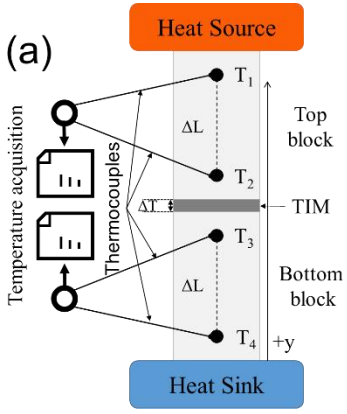


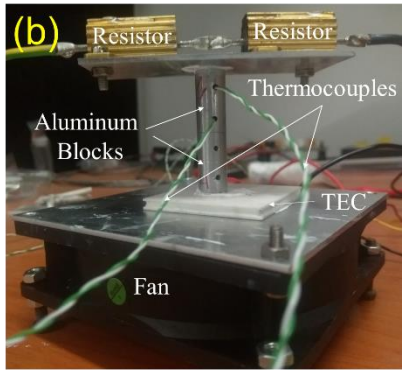


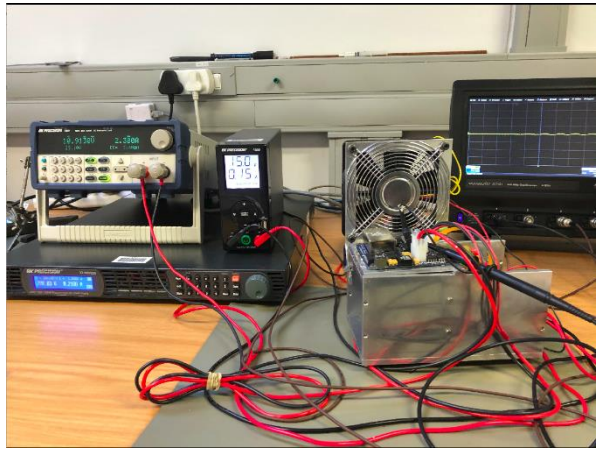


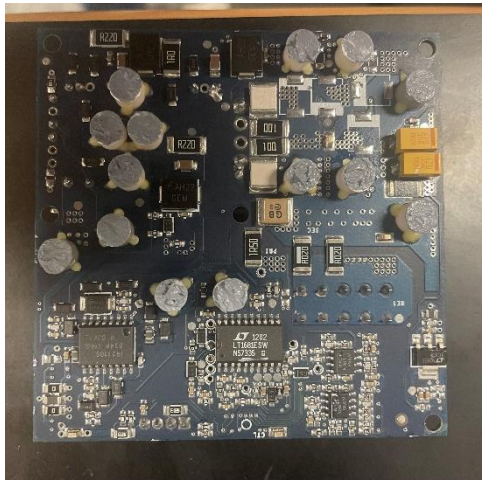
Thermal resistance and applicability on test stand

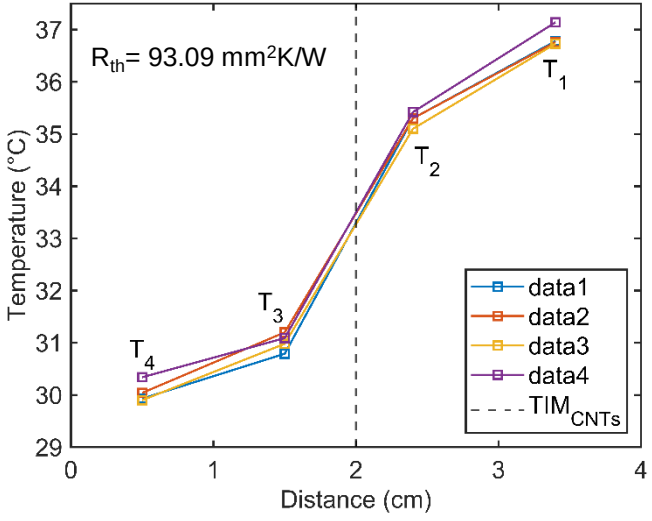
$$\Delta T = (T_2 - 0.333 \times (T_1 - T_2)) - (T_3 + 0.333 \times (T_3 - T_4))$$
$$Q = (Q_{top} + Q_{bot})/2$$
$$Q_{top} = k_{Al} \times A_{bl} \times (T_1 - T_2)/\Delta L$$
$$Q_{bot} = k_{Al} \times A_{bl} \times (T_3 - T_4)/\Delta L$$
$$R_{th} = \Delta T \times A_S/Q$$

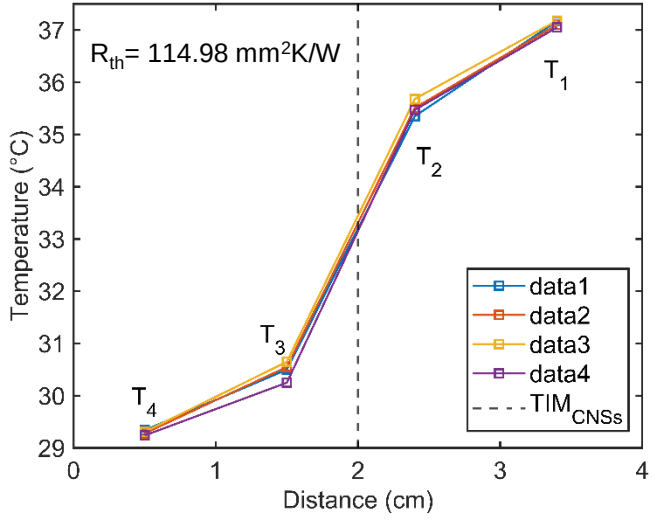




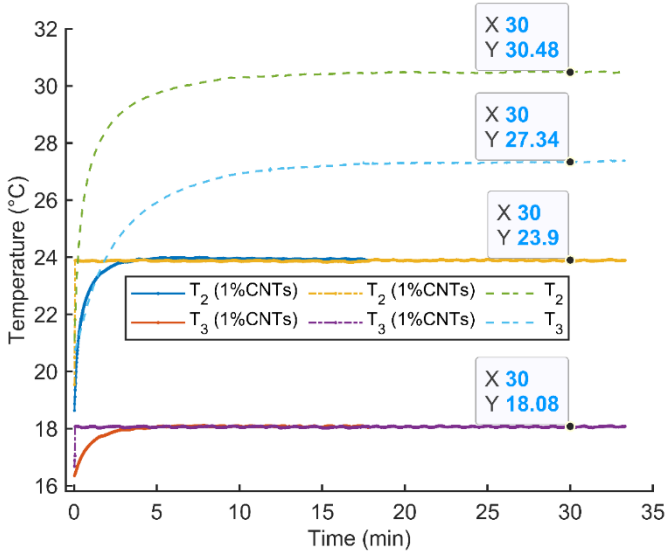




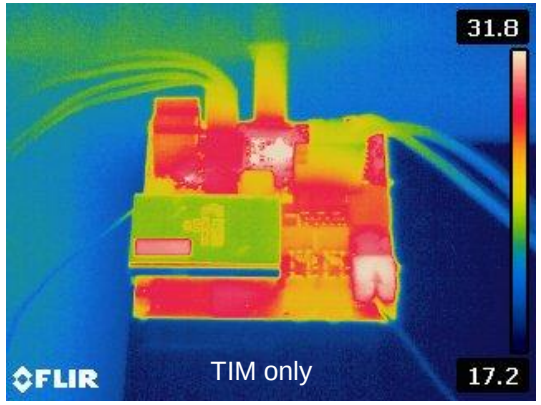


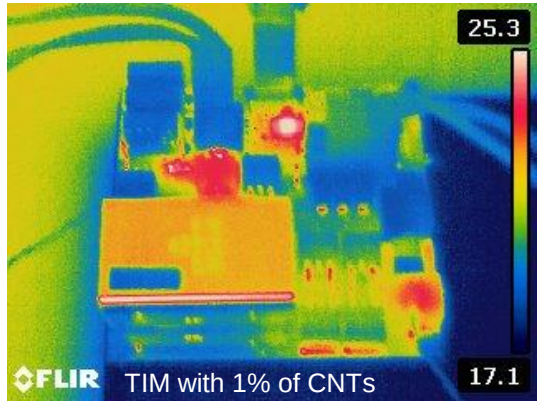


The thermal resistance R_{th} of the TIM with 1% of CNTs was calculated to be 93.09 mm²K/W, while for TIM with 1% of CNSs, it was calculated to be 114.89 mm²K/W. The thickness of the TIM between the meter blocks was estimated with the help of an optical microscope and found to be 180 µm.



The use of TIM containing 1% CNTs shows the drop of temperature T_2 from 30.48 to 23.9 °C (6.5 °C) and temperature T_3 dropped from 27.34 to 18.08 °C (9.2 °C).





Summary

- As part of the upgrade of the Atlas detector a continuous and high heat dissipation within the electronic devices is required for a good performance.
  - Integrating Carbon nanomaterials in the thermal interface materials.
- The integration of carbon nanomaterials in the epoxy showed an important enhancement of the heat dissipation in comparison to the use of only the commercial epoxy.
- The improvement is measured to reach 2 °C with a 1% of Carbon Nanotubes and 1.6 °C with 1% of Carbon Nanospheres.
- The measured thermal resistance of TIMs containing 1% of CNTs (93.09 mm^2K/W) and 1% CNSs (114.98 mm^2K/W) were in accordance with the measurements recorded by the test stand.
- This innovation in the fabrication of TIMs based on carbon nanomaterials is important for electronic devices in general as well as for the LVPS bricks in particular as it protects against overheating and damage and ensures a longer life span

Othmane Mouane, Elias Sideras-Haddad, Edward Nkadimeng, Ryan Mckenzie, Roger Van Rensburg, Bruce Mellado and Neil Coville, “***Heat Conduction Enhancement of a Thermal Interface Material for Heat Sink Applications Using Carbon Nanomaterials***,” IEEE: Transactions on Nanotechnology (under review).

Thank you